OWL and FIPA-based Knowledge Exchange in M2M communications

SSPARC Workshop

JAKUB MOSKAL
MITCH KOKAR

NORTHEASTERN UNIVERSITY & VISTOLOGY, INC.

Northeastern University

MARCH 13, 2014

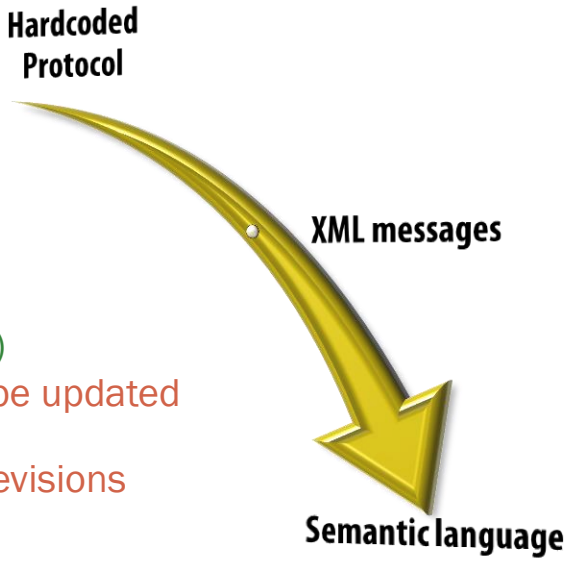
Information exchange in SSPARC

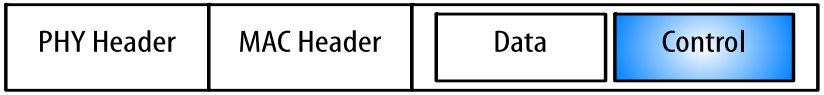
- Disclaimer: We are not supported by SSPARC and thus this slide is just our understanding about SSPARC constructed by us from publicly available information.
- Requirement:
  - Cooperative operations will require radar systems and other users to exchange information and plans **dynamically**.

- Challenge:
  - **What** information needs to be exchanged in order to agree on spectrum sharing?
  - **How** to exchange and interpret information and how to react?

Design Options

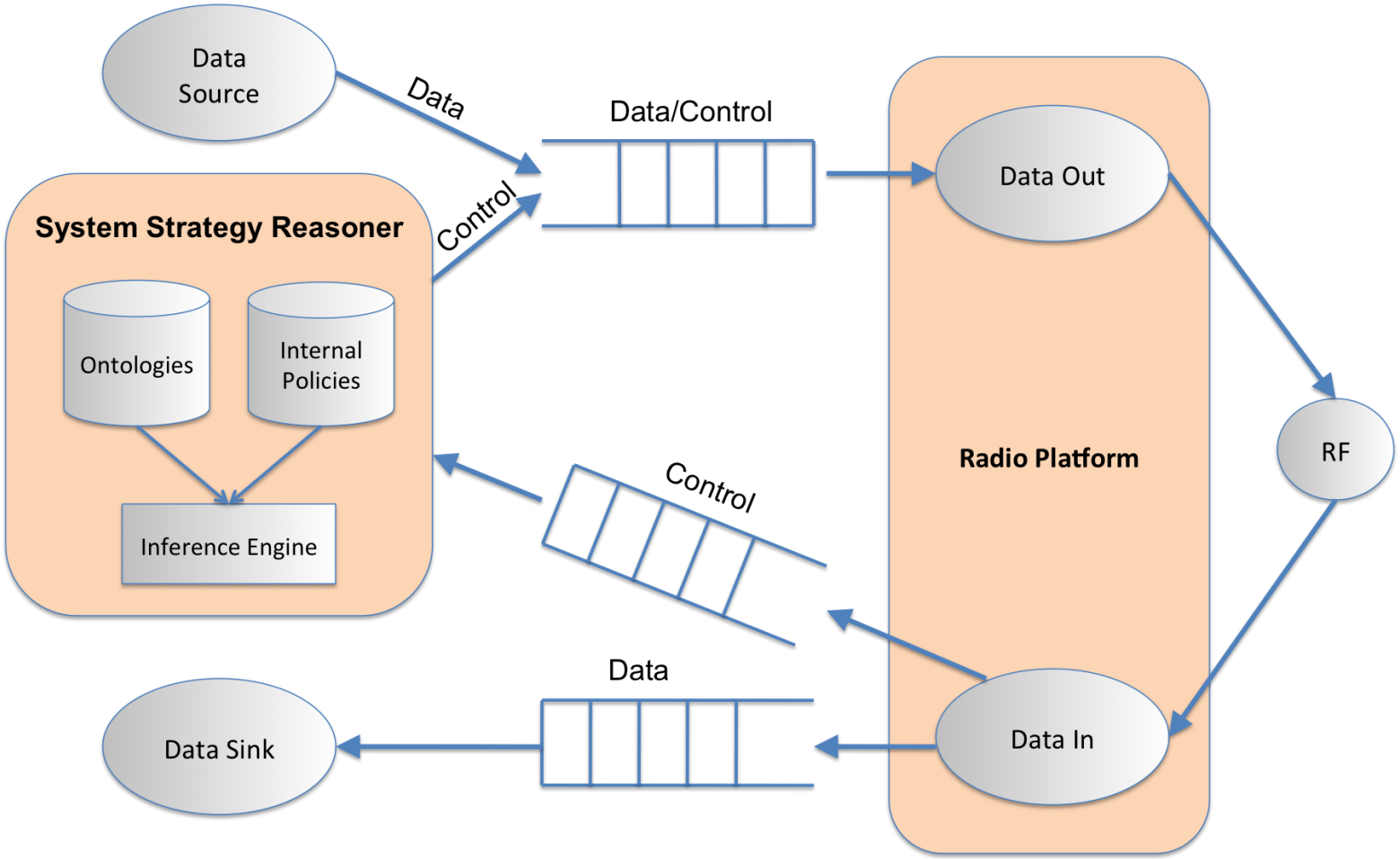
- Comprehensive Protocol
  - ✓ Efficient
  - - Bounded by the size of preamble
  - - Limited expressiveness
- XML-based signaling
  - ✓ Platform-agnostic standard
  - ✓ Can be utilized in existing protocols (messages in the payload)
  - - Requires XML-specific layer of procedural code that needs to be updated as the schema changes
  - - Backwards-compatibility may become a bottleneck in future revisions





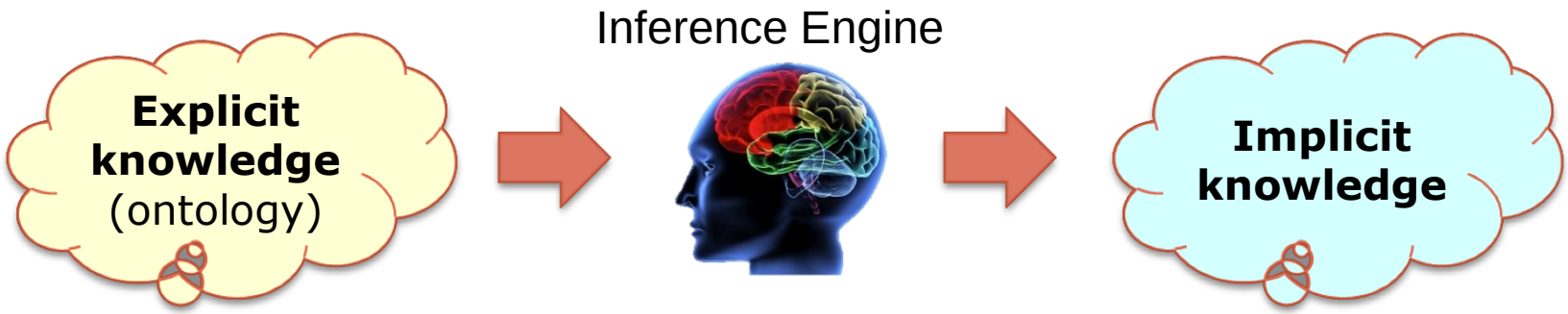
- Ontology-based, semantic signaling
  - ✓ Highly extensible, platform-agnostic standard
  - ✓ Can be utilized in existing protocols (messages in the payload)
  - ✓ Devices are equipped with a language (open for future requirements)
  - - Requires use of an inference engine (general-purpose)

Ontology-Based Radio



Formal Ontologies

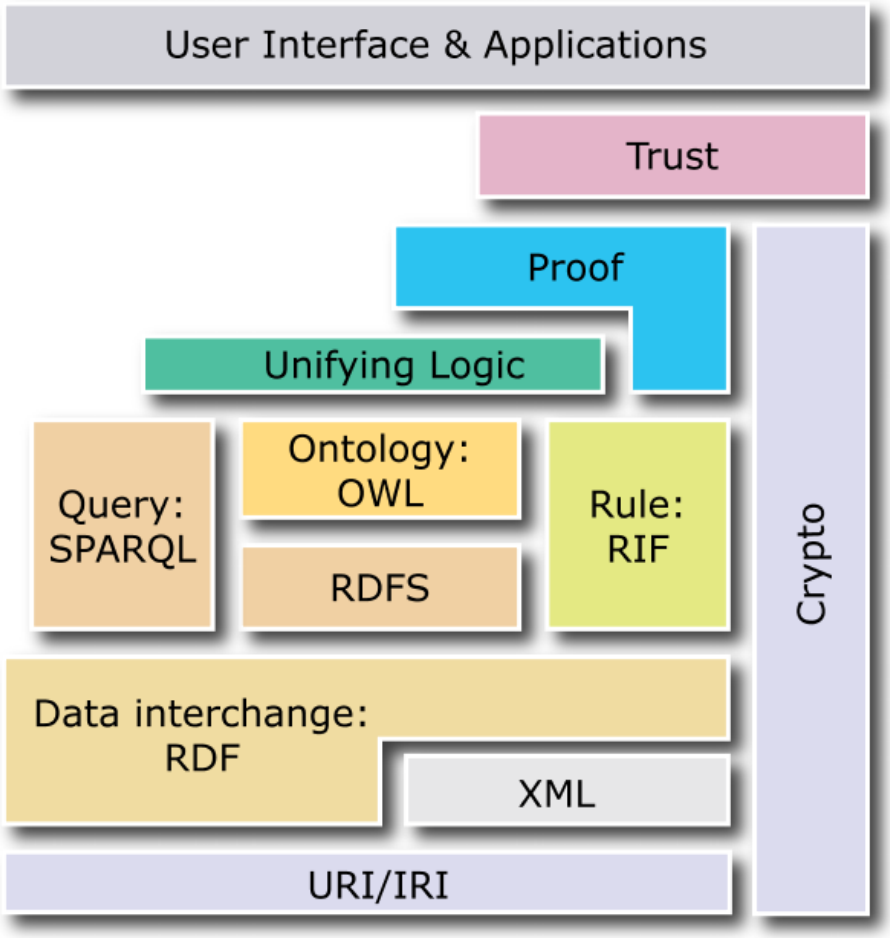
- Explicit representation of:
  - Concepts (classes, objects)
  - Relationships (relations, properties, attributes)
- Language:
  - Formal grammar
  - Machine interpretable semantics (inference capability)



Databases lack this capability.

Semantic Layer Cake

- Knowledge representation
  - OWL (Web Ontology Language) – widely adopted in the Semantic Web community
  - Semantics based on Description Logics (DL)
  - Decidable fragment of First-Order predicate Logic (FOL)
- Query Language
  - SPARQL
- Rule Language
  - Rule Interchange Format



The "Layer Cake" (Tim Berners-Lee)

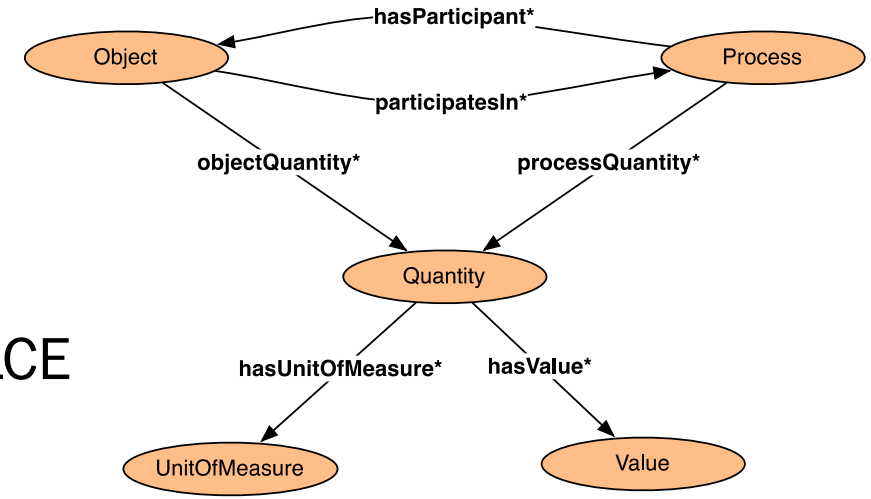
OWL 2 Complexity

- Expressiveness of OWL (species):
  - Semantics of OWL is based on Description Logics (DLs), which is a decidable fragment of First Order Logic (FOL)
  - DLs have been designed to optimize the trade-off between expressiveness and complexity of reasoning

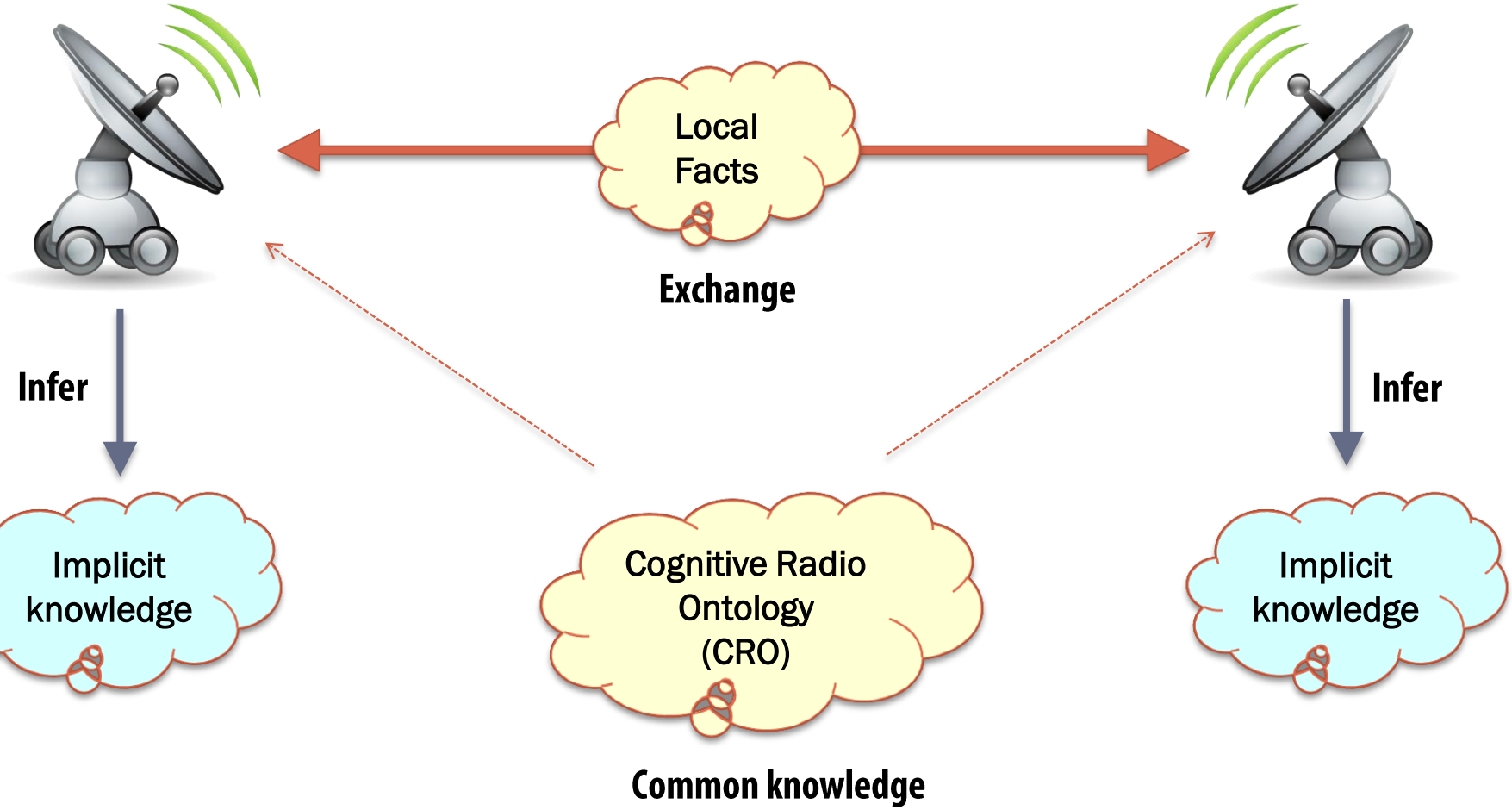
- OWL 2 RL Complexity
  - Taxonomic Complexity (wrt. size of axioms): PTIME-complete
  - Data Complexity (wrt. size of assertions): PTIME-complete
  - Conjunctive query answering: NP-complete

Cognitive Radio Ontology (CRO)

- Developed by Modeling Language for Mobility (MLM) Work Group at WINNF
  - WINNF Specification document (09/2010)
- Covers basic terms of wireless communication
  - PHY and MAC layers
  - 230 classes and 188 properties
- Top-level concepts based on DOLCE foundational ontology
  - Object
  - Process
  - Quality



Knowledge Exchange



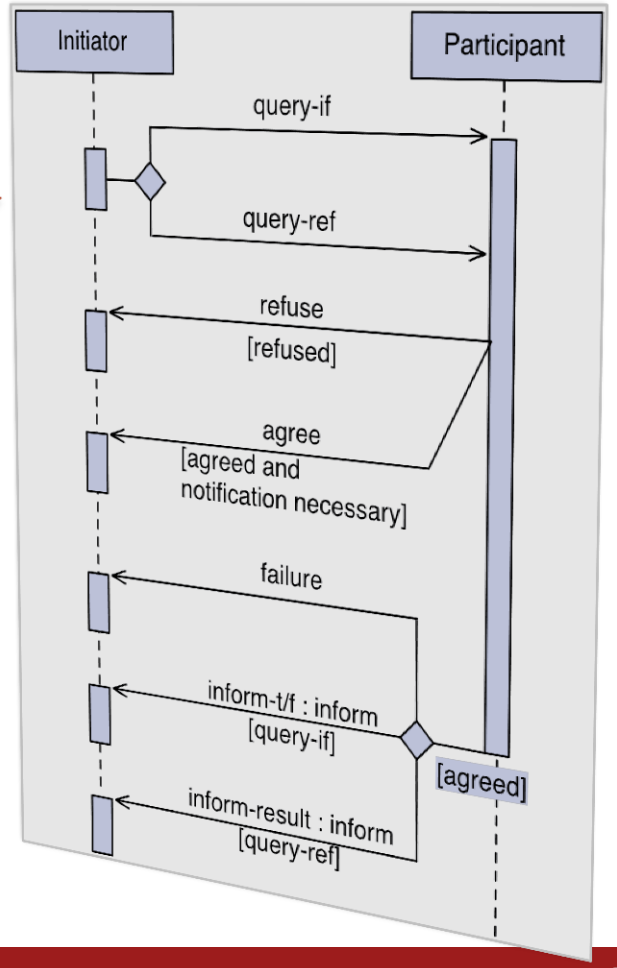
The "How" – FIPA ACL

- Foundation for Intelligent Physical Agents (FIPA)
  - Standard specification of an abstract architecture for intelligent multi-agent systems
  - Permits multiple concrete realizations
  - Supports interoperability and reusability
  - Developed by an international non-for-profit organization (FIPA)

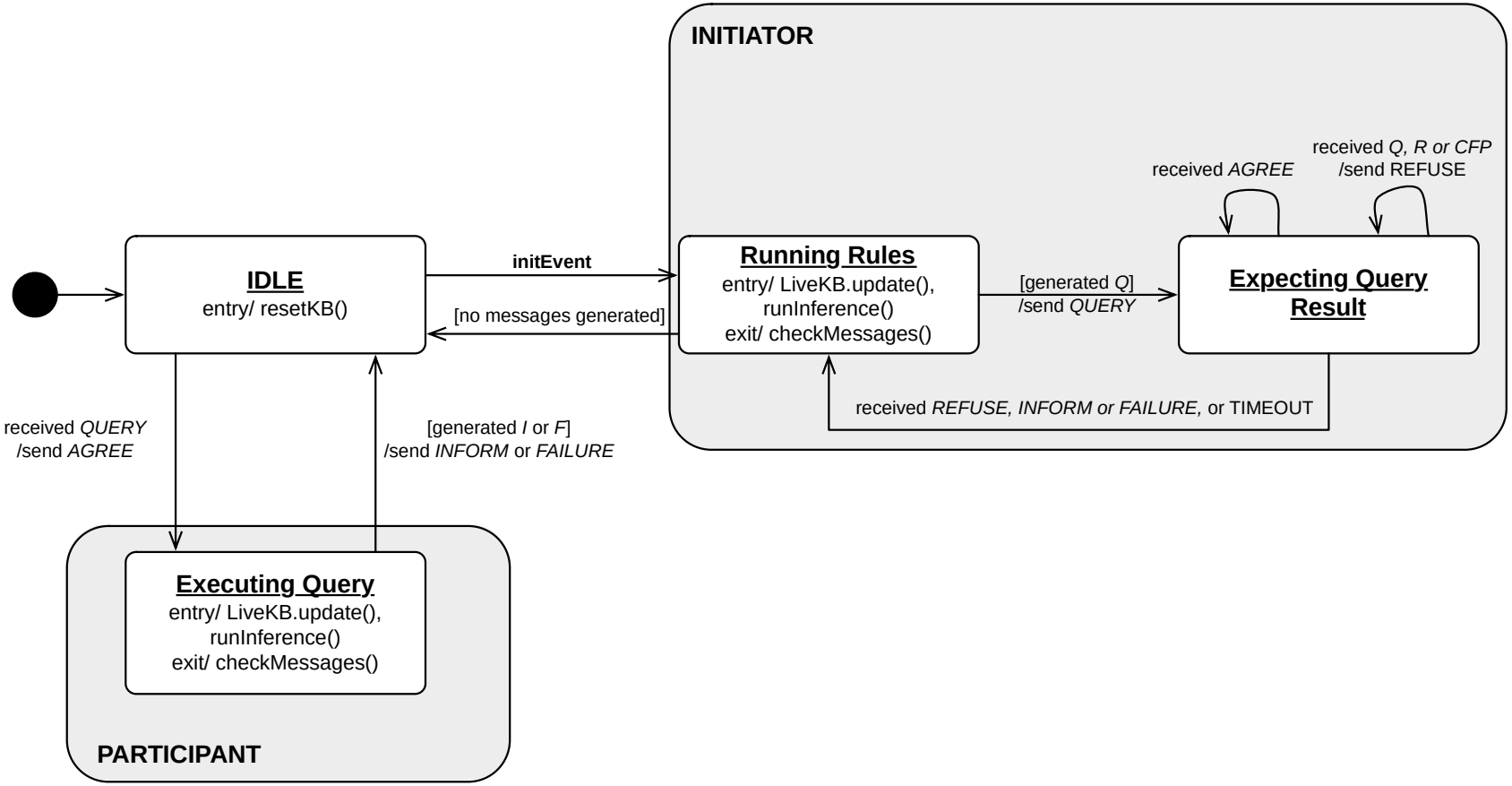
- Agent Communication Language (ACL)
  - Based on speech act theory (Pratt, 1986)
  - FIPA-ACL comprises a library of 22 communicative acts
    - Examples: confirm, inform, propose, query ref, request, reject, cancel
    - Only one is mandatory: not-understood

FIPA Interaction Protocols

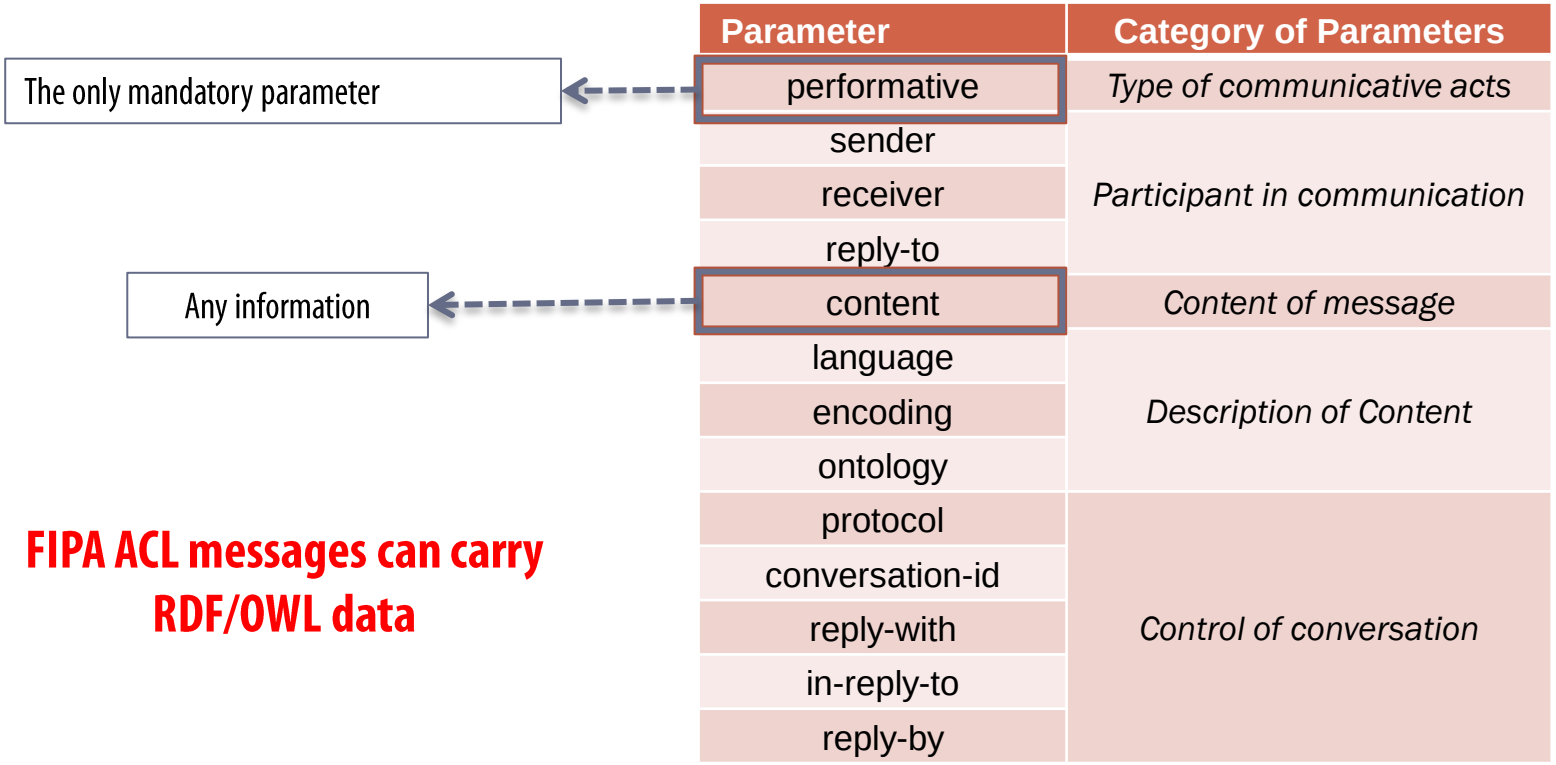
- Common patterns of message exchange
- Included protocols:
  - Request
  - Query
  - Request When
  - Contract Net
  - Iterated Contract Net
  - Dutch/English Auction
  - Brokering
  - Recruiting
  - Subscribe
  - Propose



FIPA State Machines – Query Protocol

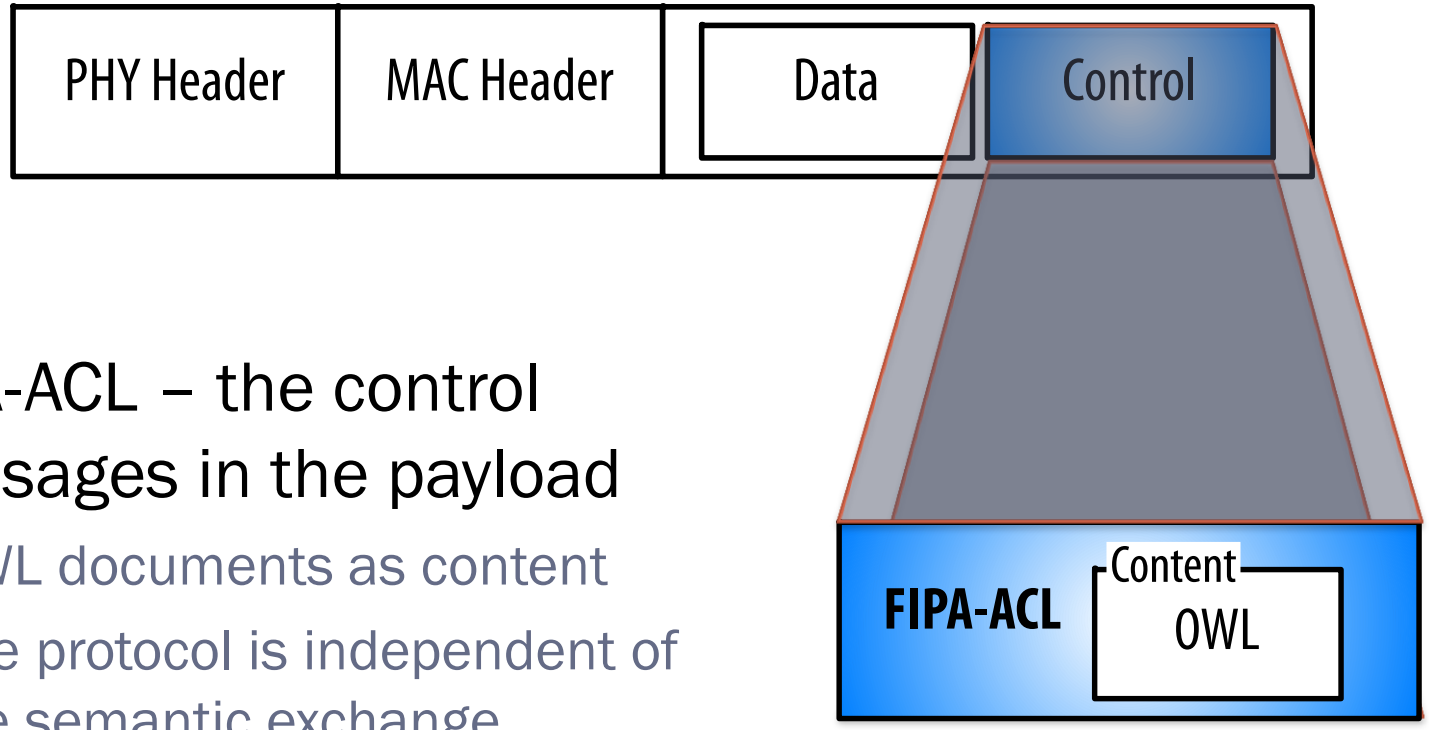


FIPA ACL Message Structure



FIPA ACL messages can carry RDF/OWL data

FIPA ACL + OWL

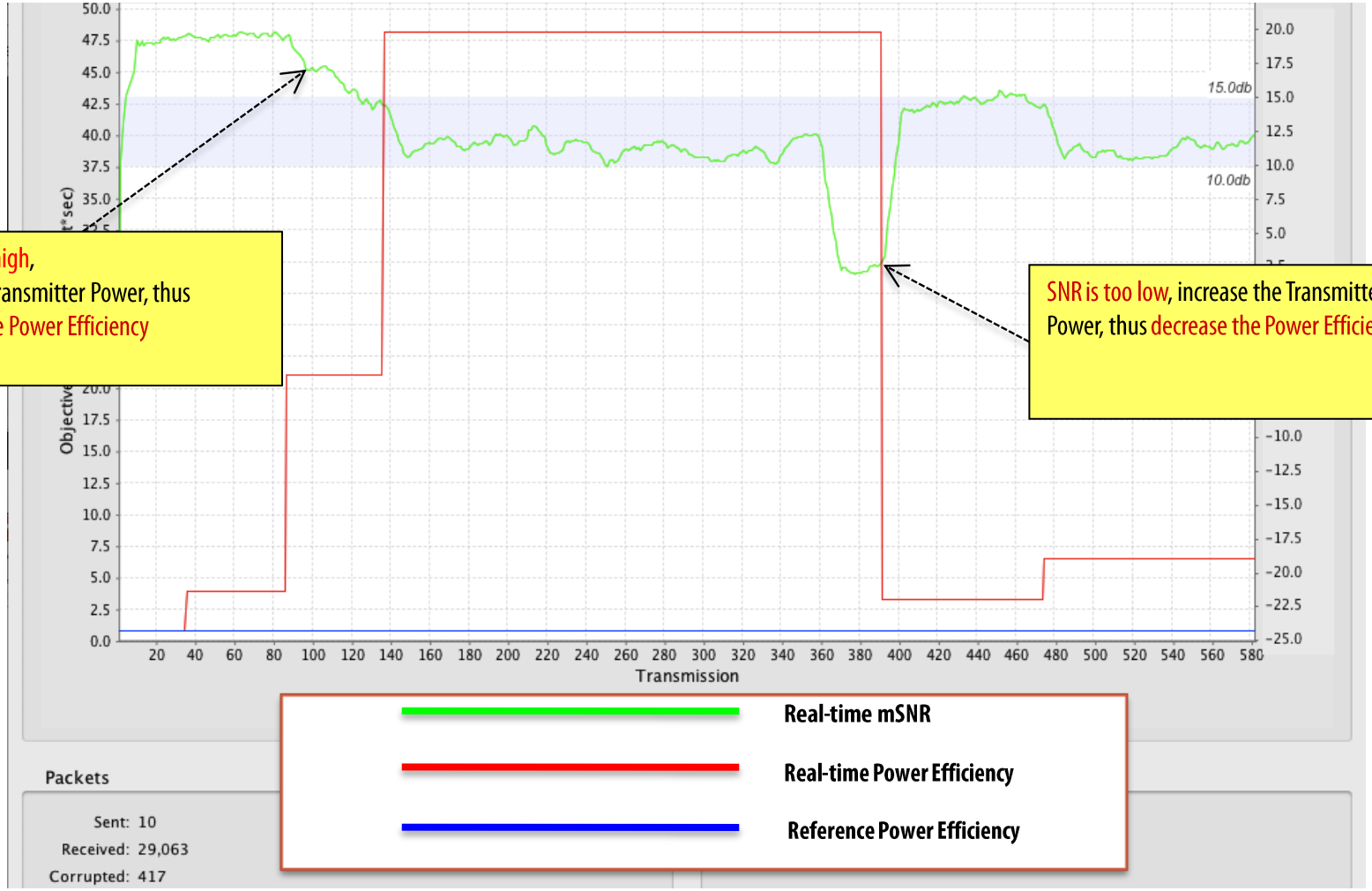


- FIPA-ACL – the control messages in the payload
  - OWL documents as content
  - The protocol is independent of the semantic exchange

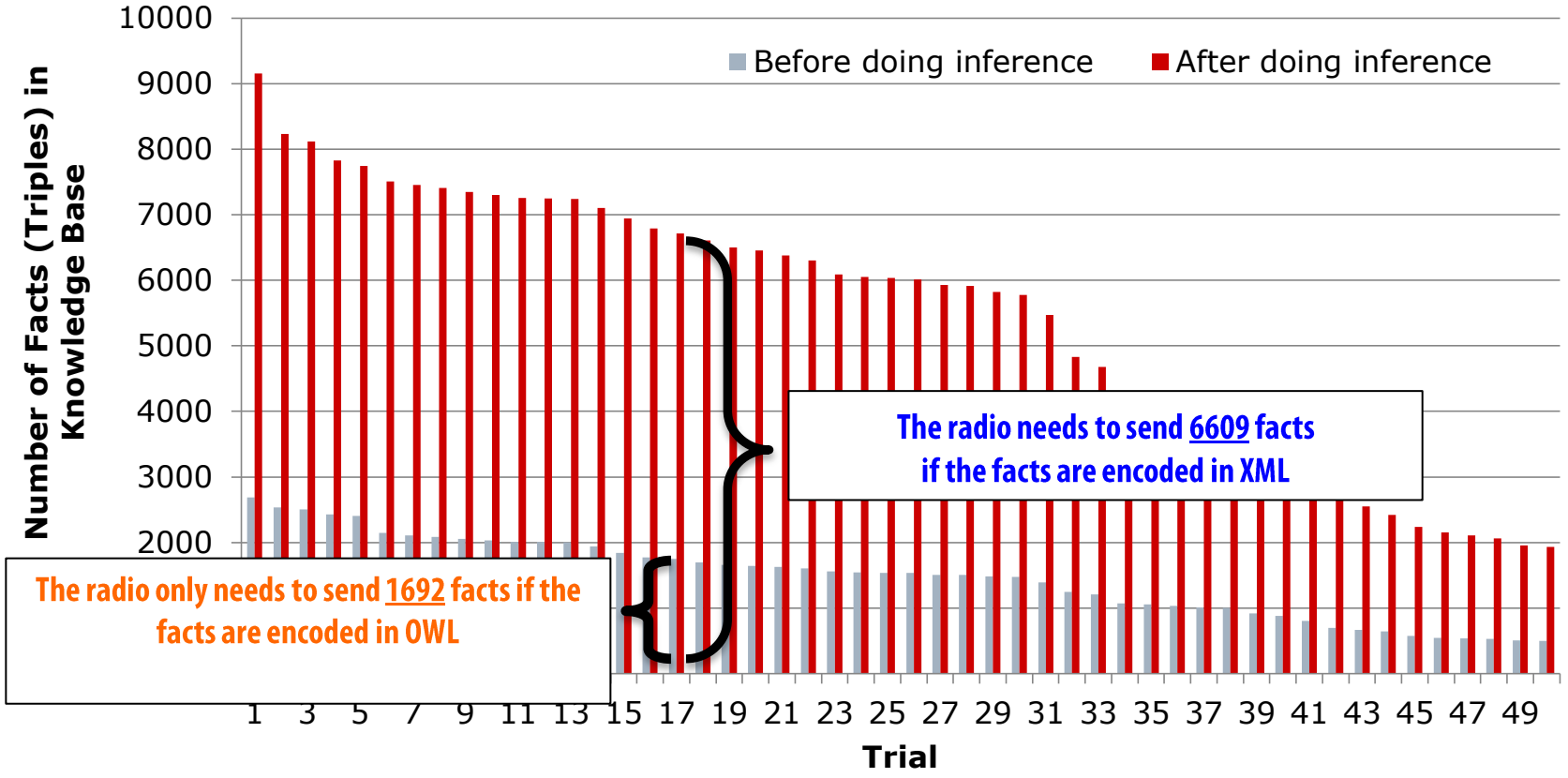
SDR'10 Proof of Concept

- USRP1, 2.4 GHz, GNU Radio
- BaseVISor as the inference engine

Adaptation Experiment



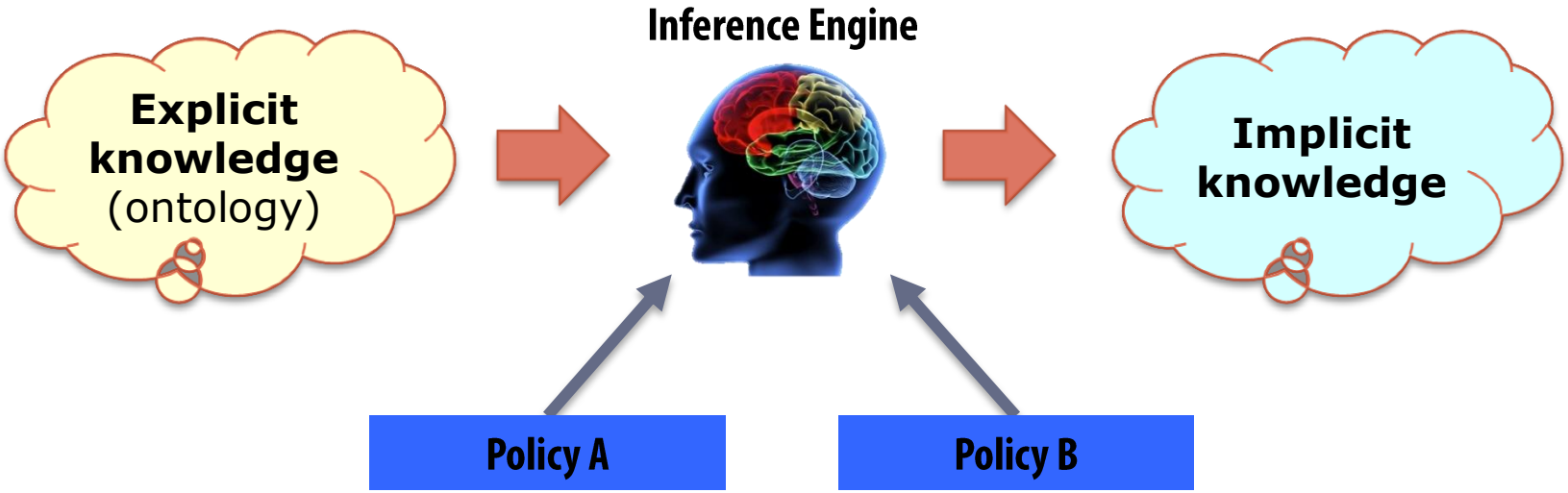
XML vs. OWL



- XML: the radio must send all the information explicitly
- OWL: the radio only needs to send parts of the information (approx. 27%),
  - ➔ Less communication overhead imposed to the network

Policy-based Radio Control

- Policy-based radio control
  - The behavior of the radio is controlled by (local) policies
  - Policies are expressed in declarative form with unambiguous semantics, e.g., OWL and rules
  - Standards Based Inference Engine: e.g., BaseVISor
- Policies are separated from implementation
  - Modification of radio behavior becomes flexible
  - Simpler certification process
  - Represent policies at a more abstract level and with easier understood semantics



Conclusions

- Semantic-based approach offers great flexibility:
  - Ease of modification and protocol extension
  - Rich expressiveness
  - Human-readability
  - Flexibility of the length, ordering and selection of control information
  - Does not require introducing a new communications protocol (only Application Layer protocol – FIPA ACL)

Thank You